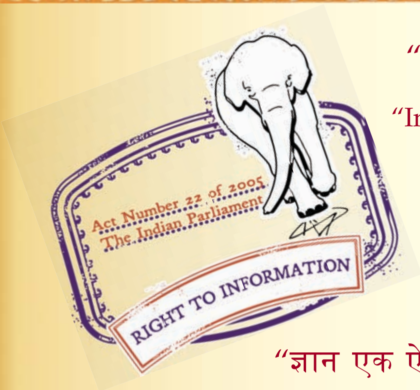
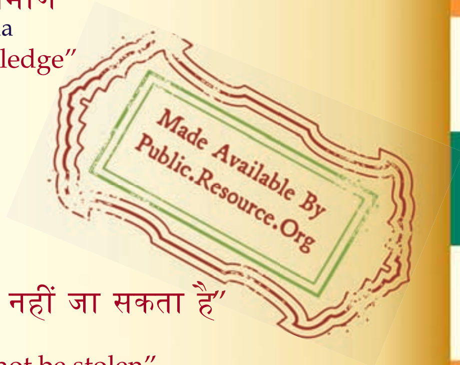
IS 6955 (2008): Subsurface exploration for earth and rockfill dams - Code of practice [WRD 5: Gelogical Investigation and Subsurface Exploration]





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भारतीय मानक

भूमि और चट्‌टान भरे बाँधों के लिए उपसतह का अन्वेषण — रीति संहिता

(पहला पुनरीक्षण)

Indian Standard

SUBSURFACE EXPLORATION FOR EARTH AND ROCKFILL DAMS — CODE OF PRACTICE

(First Revision)

ICS 93.020

BUREAU OF INDIAN STANDARDS
MANAK BHAVAN, 9 BAHADUR SHAH ZAFAR MARG
NEW DELHI 110002

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Geological Investigations and Subsurface Exploration Sectional Committee, WRD 05

FOREWORD

This Indian Standard (First Revision) was adopted by the Bureau of Indian Standards, after the draft finalized by the Geological Investigations and Subsurface Exploration Sectional Committee had been approved by the Water Resources Division Council.

This standard was first published in 1973. The present revision is proposed to reflect the experience gained on the subject since then.

Earth and rockfill dams have been constructed since early ages. The dams built in olden days, were generally of low to medium heights. With increasing heights of dams and faster rates of construction, there is a greater need for proper investigations and design based on the latest developments in the fields of soil and rock mechanics. An important requisite for proper design is adequate investigation. Subsurface explorations form an important part of these investigations.

It has been assumed in formulating this standard that the execution of its provisions is entrusted to appropriately qualified and experienced people, for whose guidance it has been formulated.

For the purpose of deciding whether a particular requirement of this standard is complied with, the final value, observed or calculated, expressing the result of a test, shall be rounded off in accordance with IS 2 : 1960 'Rules for rounding off numerical values (*revised*)'. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

Indian Standard

SUBSURFACE EXPLORATION FOR EARTH AND ROCKFILL DAMS — CODE OF PRACTICE

(First Revision)

1 SCOPE

1.1 This standard gives guidance on the type, extent and details of subsurface explorations needed in connection with earth and rockfill dams. It is not possible to lay down the required extent of exploration to cover all types of cases. The standard provides guidelines for planning the exploratory work through various stages of the project development. These recommendations may have to be modified for individual projects depending upon the site conditions and other conditions peculiar to each project, such as, height, importance of the dam and the heterogeneity of foundation formations.

1.2 The term subsurface exploration, as used herein, covers all types of exploration connected with determination of the nature and extent of soil and/or rock below the natural ground surface at/or near the dam site.

1.3 This Code does not however cover the types and methods of exploration for materials of construction for earth and rockfill dams, such as, soil, rock and material for riprap protection. These will be covered by a separate Code on subsurface exploration for construction materials.

2 REFERENCES

The standards listed in Annex A contain provisions which, through reference in this text, constitute provisions of this standard. At the time of publication, the editions indicated were valid. All standards are subject to revision and parties to agreements based on these standards are encouraged to investigate the possibility of applying the most recent editions of the standards indicated in Annex A.

3 GENERAL CONDITIONS

3.1 The type and extent of exploration should be commensurate with the size and importance of the project and will depend upon the size of the dam and the type of foundation. These should neither be too little, resulting inadequate data, nor too much, resulting in excessive cost and time for investigation (*see* IS 15662).

3.2 Subsurface explorations in connection with an earth and/or rockfill dam would cover a specified area around the dam site and will be carried to a specified depth. A complete programme of exploration should be able to give information regarding the following points:

a) Types of different soil and rock masses that exist in the foundation and abutments.

b) The location, sequence, thickness and areal extent of each soil/rock stratum, including a description and classification of the soil and their structure, stratification in the undisturbed state, significant geological or other structural features, such as, buried channels, seams, joints, fissures, and mineral and chemical constituents.

c) The depth to and type of bedrock as well as the location, sequence, thickness, areal extent, attitude, depth of weathering, soundness, , description and classification of rock in each rock stratum within the depth of exploration.

d) The characteristics of the ground water, including whether the water table is perched or normal, direction of flow of ground water, depth of and pressure in artesian zones, and quantity of dissolved salts present in the ground water.

e) Engineering and index properties of the over burden and physical characteristics of rocks.

f) Seismo-tectonic set up of the project region.

4 STAGES OF EXPLORATION

4.1 The extent of foundation exploration required for a dam of given size varies greatly from site to site depending on the subsurface conditions and cannot be adequately visualized in advance. The exploration generally proceeds in stages, the details of each stage growing out of the one before. It normally follows a learn-as-you-go procedure in which characteristics of the subsurface soils and conditions are developed in progressively greater detail as the

exploration proceeds.

4.2 Explorations can be generally sub-divided into four stages as in 4.2.1 to 4.2.4.

4.2.1 *Reconnaissance or Pre-feasibility Stage*

This should comprise of selection of suitable alternative sites on the basis of regional and local geology, topographic expression and anticipated depth to bed rock and impermeable strata. This will consist of photo-geological interpretation and a general field inspection by qualified engineering geologists and engineers for an assessment of the overall aspects of the geology of the site and foundation conditions. On the basis of information gathered at this stage, an evaluation is made about the depth and characteristics of foundation strata, which would serve as a basis for initial planning of the programmes of field work, which will broaden or add to the existing knowledge of the site conditions and the methods and scope of investigations and testing.

4.2.2 *Preliminary Investigation or Feasibility Stage*

4.2.2.1 *Objectives and methods of exploration*

During this stage, necessary data for formulation of the project would be collected. The coverage of exploration should be adequate for examination of the feasibility, which includes estimation of the cost and evaluation of the benefits. This stage would also include studies for preliminary choice of the alignment as well as the height of the dam. This stage of exploration includes the following types and methods of investigations:

a) Exploration by test pits, trenches, drifts and shafts;

b) Exploration by geo-physical methods;

c) Exploration by drilling using coring and non-coring methods or by other boring methods;

d) Determination of the depth to water table and evaluation of field permeability; observation of temperature, pressure and discharge of springs met at the surface or in exploratory borings, trenches, etc;

e) Field penetration and field density tests in overburden; and

f) Laboratory tests on representative samples and undisturbed samples for the determination of engineering and index properties of the overburden material/ bedrock.

4.2.2.2 *Choice of methods*

For dams upto 30 m height exploration by trial pits, trenches and drill holes should be sufficient. For dams upto and above100 m height and above, additional exploration by drifts and shafts may be required depending upon the geological complexity of the site.

4.2.2.3 *Spacing of test pits/drill holes*

For dams less than 30 m in height, exploration by pits at a spacing of 250 m to 300 m depending upon the nature of the foundation material may be necessary. For dams over 30 m in height, the spacing between drill holes may be decided so as to have minimum 5 numbers of drill holes with particular attention being given for adequate coverage to deeper sections. In between drill hole locations, trial pits or auger holes would be sufficient (*see* IS 4453).

4.2.2.4 *Location*

Exploratory holes, pits and auger holes may be located along the axis of the dam for dam up to 100 m height. For dams greater than 100 m, however, additional line of holes may be necessary depending on geological conditions (*see* IS 4453).

4.2.2.5 *Depth of exploration*

In general, the depth up to which explorations should be made depends upon the following factors:

a) Depth of overburden and depth up to which weathering of bed rock has progressed. Exploration should be carried to a depth to locate all weak and compressible or otherwise undesirable layers in the foundation, such as buried channels.

b) At the preliminary investigation stage, the depth would be generally guided by the permeability characteristics of the strata. It may be sufficient to explore up to a depth of $\frac{1}{3}$ or $\frac{1}{2}$ of the hydraulic head at the location of the dam if rock is found at shallow depths of less than $\frac{1}{3}$ to $\frac{1}{2}$ of the hydraulic head. If the depth to rock is larger than $\frac{1}{3}$ or $\frac{1}{2}$ the hydraulic head, one or two drill holes may be taken down to 10 m into the *in-situ* rock.

4.2.3 *Detailed investigation or DPR stage*

4.2.3.1 In this stage of investigation, all data required for detailed design and preparation of construction drawings should be collected. Close co-ordination is essential between the work of the

organizations for exploration, geology and design. The design engineer and the geologist should be closely associated with the exploration and they should be required to prepare an outline of the scope and extent of exploration. While the details would be left to those incharge of exploration, the designer and the geologist should participate in the choice of the method of investigation and the equipment, so that they can appreciate the limitations of the data obtained through field work.

4.2.3.2 Investigations at this stage would comprise the following:

a) Intensive exploration by additional drilling and pitting (trenches, adits and shafts, where found necessary) of the foundation/abutment to determine spatial distribution and characteristics of different types of foundation materials in relation to specific design features;

b) Use of geophysical methods to define in greater detail the subsurface conditions, such as the depth to bed rock or depth to water table in specific sections of the dam base. During this stage, use of bore hole geophysical methods, such as electric logging, GPR, tomography, etc (as and when required) may be found advantageous to define particular characteristics of over burden and bed rock;

c) Defining of geohydrological characteristics of the foundations and its environments through pumping in or pumping out tests as dictated by site conditions;

d) Ascertaining the groutability of foundations through trial grouting of specified reaches;

e) Special field tests like blasting tests and field shear tests, where found necessary; and

f) Seismo-tectonic set up of the project region.

4.2.3.3 *Depth and spacing of holes*

a) For dams less than 30 m in height, one additional line of holes (in addition to those indicated in **4.2.1**) as per design considerations may be necessary. The holes should be suitably staggered to provide information at 30 m intervals. The depth of 1/3 of these holes may be kept equal to the hydraulic head of the dam.

b) For dams 30 m to 100 m in height, two additional rows of holes would be required. The spacing between drill holes may be 1/10th of the length of the portion with particular attention being given for adequate coverage to deeper sections. Half the number of holes should be taken to depths equal to the hydraulic head and the remaining to half the hydraulic head or to a depth to prove a continuous impervious soil or rock or such strata that can be rendered impervious by treatment. The depths to which exploration should be continued in the impervious medium or medium that can be rendered impervious by treatment should be decided on the basis of design considerations.

c) For dams above 100 m in height, three lines of holes should be drilled at locations as per design considerations. The depth of these holes should be equal to the hydraulic head. In addition, trenches to explore the foundation sequence in the river bed section and for collection of undisturbed samples may be required.

For a dam more than 100 m height, three or more drifts on either bank with cross cuts are recommended. However, the length of the main drift and the cross cuts will depend upon the dimension of the structure (dam section across and along the river flow) at that particular elevation, meaning thereby that the length of the main drift and cross cuts will be more near the base and reducing gradually towards the top of the dam. The length of the drift should be decided by the engineering geologist as per design requirement, which in turn depend on the height of the dam and quality of the rockmass. These drifts can be utilized for various purposes, namely, inspection, drainage and grouting at a later stage. The groutability of foundation through trial grouting of the specific section, in a set pattern, should also be tested during this stage.

4.2.4 *Construction Stage*

During this stage, large scale geological investigations are carried out to delineate all geological and structural features exposed on the foundation of the dam and its appurtenant structures and to apprise the construction and design engineers regarding rock mass structure and any special geo-structural features, like, fault zones, deformed/weak zones, breccia zones, shear, etc, which require dental or any other suitable treatment, like, grouting for strengthening rockmass and making them water tight. The shear zones, deformed zones or weak zones should be marked with colour paint on the foundation

surface. The final foundation grade geological mapping should be done on 1:100 scale with 1 m contour interval in grid pattern (2m × 2m) using high precision survey equipment like total station. The foundation surface should be properly cleaned by air or water jet before taking up geological mapping, which guides the foundation preparation and treatment.

5 METHODS OF EXPLORATION

5.1 The following categories of methods may be used for subsurface exploration for earth and rockfill dams:

a) Geophysical,
b) Pits and trenches,
c) Borings (auger boring and core drilling),
d) Shafts and drifts, and
e) *In-situ* tests.

5.1.1 Geophysical explorations enable gaining of knowledge of properties of subsurface strata by inference from measured rates of transmission of electric current or seismic waves. *In-situ* tests enable direct measurement of properties in the ground. The rest are means of visual examination, collection of samples and for performance of laboratory tests thereon.

6 GEOPHYSICAL OBSERVATIONS

6.1 Geophysical methods can, under appropriate conditions, be used to obtain in relatively very short time, information regarding the nature of the various strata and their position and depths of change. However, since it is not a direct measurement, borings have to be made for correlation in order to interpret correctly the geophysical data.

6.2 The geophysical methods are not adequate in themselves as tools for subsurface investigation. Whereas they permit a fast coverage of the entire area at low cost, and the process is not hampered by presence of boulders, etc, which generally produce obstruction in boring, the correct interpretation of geophysical observations is difficult, particularly in areas of irregular formations and irregular depths of strata and steep topography. It is, therefore, imperative that interpretation from geophysical work be confirmed by borings.

6.3 Geophysical investigations should always be carried out with proper equipment by properly trained and experienced investigators, because accuracy in observations and interpretation of data is very essential for arriving at reliable conclusions.

6.4 The principal or main methods applicable in case of explorations for dams are:

a) Seismic refraction, and
b) Electrical resistivity.

6.4.1 *Seismic Refraction Method*

Earth vibrations set up artificially by explosions form the basis of this method. The earth waves travel in all directions through the ground and are refracted or reflected back to the surface by lower rock formation through which they travel with a different velocity than through the overburden. The time of arrival of these waves at any point on the surface of the ground is recorded by a special seismograph and the time of travel from the explosion point to the pick-up point is thus determined. This information enables deductions to be drawn regarding nature and depth of underlying formations.

6.4.1.1 This method may be used to determine the depth to bedrock, the dip in special cases and other data regarding the underlying rock formations which are useful for designing foundations for dams, such as dynamic modulus from shear wave velocity and vibration characteristics of the foundation. These studies may be required in special cases of weak rocks and high dams (*see* IS 15681).

6.4.2 *Electrical Resistivity Method*

This generally uses four electrodes at equal distances along a straight line. An electric current is passed between the outer two electrodes and is precisely measured by a milliammeter. The potential difference between the inner two electrodes is measured using null point type of circuit. From the data obtained, the electrical resistivity is calculated.

6.4.2.1 The value of apparent resistivity changes at each change of strata and since, in general, the distance between the electrodes is equal to depth of layer being measured, it is by this method possible to measure specific resistance to different depths by varying the electrode spacing. With some knowledge of the local geology and of the typical values for different strata, it is possible to determine the thickness and depth of the different strata by use of one or more methods of interpretation, namely mathematical analysis, empirical methods, inter-correlation with curves and correlation with model experiments. As regards dams, this method can be employed for locating bedrock and water table (*see* IS 15736).

7 EXPLORATION BY PITS

7.1 Deep trial pits (*see* IS 4453) may be used to investigate open fissures, or to explore zones of weak rocks, which would break up in the core barrel and are incapable of being recovered in tact. In case of

dams, open pits are useful for investigating the nature of overburden in foundation area.

7.2 At the surface the excavated material shall be placed in an orderly manner around the pit and marked stakes shall be driven to indicate depth of pit from which the material came, in order to facilitate logging and sampling.

7.3 The level of the water table and the level, location and rate of seepage flow in the test pit should be date-wise recorded.

8 EXPLORATION BY TRENCHES

8.1 Exploration by trenches (*see* IS 4453) is useful in providing a continuous exposure of the ground along a given line or sections. They are best suited for shallow explorations (3 m to 4.5 m) on moderately steep slopes, for example, abutment of dams.

8.2 The profile exposed by these trenches may represent the entire depth of significant strata in an abutment of a dam. However, their shallow depth may limit explorations to the upper weathered zone of foundations.

8.2.1 Trenching permits visual inspection of the soil strata, which facilitates logging of the profile and selection of samples. It also aids in obtaining large undisturbed samples for testing. Trenches in sloping ground have the advantage of being self-draining.

8.3 The level of the water table and the level, location and the rate of seepage, if met with, should be date-wise recorded.

8.4 The length and spacing will be determined on the basis of height and length of dam and geological complexities.

9 EXPLORATION BY BORINGS

9.1 Borings provide the simplest method of subsurface investigation and sampling. They may be used to indicate the subsurface stratum and to collect samples from each of the strata.

9.2 Borings may be made by several methods depending upon the nature of subsoil strata, as detailed below:

Sl No.	*For Soils*	*For Rocks*
(1)	(2)	(3)
i)	Post hole auger (*see* IS 1892)	Percussion boring
ii)	Shell and auger boring (*see* IS 1892)	Rotary drilling (*see* IS 1892)
a)	Mud-rotary drilling	
b)	Core drilling (*see* IS 6926)	
c)	Short drilling (*see* IS 1892)	
iii)	Wash boring (*see* IS 1892)	
iv)	Rotary drilling (*see* IS 1892)	

9.3 Auger Boring

9.3.1 *Post-Hole Auger*

Hand-operated post-hole augers, 100 mm to 300 mm in diameter, can be used for exploration up to about 6 m. However, with the aid of the tripod, holes up to 25 m depth can be excavated. Depth of auger investigations are limited by ground water table and by the amount and maximum size of gravel, cobbles and boulders, as compared to size of equipment used.

9.3.1.1 Mechanically operated augers are also available and are particularly suitable, where a large number of holes are to be made, or in gravelly soils. Machine driven augers are of three types and are given below:

a) Helical augers : 75 mm to 400 mm in dia
b) Disc augers : Up to 1 050 mm in dia
c) Bucket augers : Up to 1 200 mm in dia

9.3.1.2 An auger boring is made by turning the auger to the desired distance into the soil, withdrawing it and removing the soil for examination and sampling. The auger is inserted in the hole again and the process is repeated. Holes are usually bored without addition of water in loose, moderately cohesive moist soil. But in hard dry soils or cohesionless sands, the introduction of a small amount of water into the hole will facilitate the drilling and sample extraction.

9.3.2 *Shell and Auger Borings*

Pipe casing or shell is required in unstable soil in which the bore hole collapses, and especially where the boring is extended below the ground water level. The inside diameter of the casing should be slightly larger than the diameter of the auger used. Borings up to 200 mm diameter and 5 m depth can be done with manual operation. Power winch is required for deeper borings. The casing is driven to a depth not greater than the top of the next sample and is cleaned out by means of the auger.

9.4 Core Drilling

9.4.1 Core drilling should be done in accordance with IS 6926 (*see also* IS 4078 and IS 4464).

9.4.2 The accuracy and dependability of the records

furnished by diamond drilling depend largely upon the size of the core in relation to the kind of material drilled, the percentage of core recovery, the behaviour during drilling and the experience of the drill crew. Largest practicable diameter core should be obtained. Recovery of core is much more important than rapid progress in drilling the hole. When drilling in soft materials, the water circulation should be reduced or stopped entirely and the cores be recovered dry.

9.4.3 Detailed history of mechanical operation of drilling including observations on the loss of return water and its reappearance, difficulties encountered and time taken in these difficult areas and in areas of core loss should be included in the drilling report.

9.4.4 Percolation tests under specified pressures should be done in drill holes using packers, as the drilling progresses.

9.4.5 Completed holes should be capped to preserve them for use in ground water level observations or as grout holes or for re-entry, if it is later found desirable to deepen the hole.

10 EXPLORATION BY DRIFTS

10.1 Drifts or tunnels (*see* IS 4453) are normally employed to explore at depth the continuity or character of subsurface formations. They are most frequently used for the investigation of fault or shear zone, buried channels and suspected places of weakness in dam foundation, abutments and beneath steep slopes or back of cliff like faces to determine the extent of weathering, slump zone and bed rock configuration in areas of fossil valleys.

10.1.1 They are also used for taking undisturbed samples of rock for tests in the laboratory and for performing *in-situ* tests like the plate bearing test and flat jack tests to determine the modulus of elasticity and deformation of rock formations and shear, etc, required to study the properties of the rock.

10.2 Logging and sampling of exploratory drift should proceed concurrently with excavation operation. They should be mapped giving direction of dip, fault zones, shear zones and seams, etc. as detailed in IS 4453.

10.3 Level, location and piezometric heads of seepage flows, if any, occur should be recorded date-wise.

11 EXPLORATION BY SHAFTS

11.1 Shafts (*see* IS 4453) are vertical holes and are normally employed to reach a particular point at a great depth, either to extend the exploration below river bed by means of drifts for dam foundation or for exploring locations of structures, such as gates, underground diversion tunnels, penstocks, etc. They also provide continuous exposures of the ground along the direction of shaft.

12 *IN-SITU* TESTS

12.1 *In-situ* field tests are those, in which the material is tested without actual removal of the material from its existing position. The *in-situ* tests applicable to earth and rockfill dams are the following:

a) Strength tests:
   1) Deep penetration tests, and
   2) Shear tests.
b) Measurement of density of foundation material,
c) Permeability tests, and
d) Blasting tests.

12.1.1 The necessity and the number of each type of test to be conducted depend on the foundation material and its degree of variability.

12.2 Strength Tests

12.2.1 *Deep Penetration Tests*

12.2.1.1 These tests [*see* IS 2131, IS 4968 (Part 1), IS 4968 (Part 2) and IS 4968 (Part 3)] consist of measuring the resistance to penetration under static or dynamic loading of different shaped tools. The tests are empirical and have been developed from experience. They should be performed carefully in the prescribed manner.

12.2.1.2 Static and dynamic penetration tests in bore holes or direct provide a simple means of comparing the results of different bore holes on the same site and for obtaining an indication of the bearing value of the soils, and of the state of densification of non-cohesive soils. Correlation between number of blows obtained in standard (dynamic) penetration tests (*see* IS 2131) and between penetration resistance in static penetration test with bearing capacity and relative density of non-cohesive soils are given in several publications (*see also* IS 6403). While these can be used as guides, a better method would be to do actual calibration of the apparatus, or at least use more than one method for comparison.

12.2.1.3 Where dams are to be founded on sandy deposits, these tests are suitable methods for determining *in-situ* densities at depth, which is vital for assessment of settlements, and of potentialities of liquifaction under earthquakes.

12.2.1.4 The number of tests should be fairly large enough to cover the entire critical foundation area.

12.2.2 *Shear Tests*

12.2.2.1 *Vane shear tests*

These tests (*see* IS 4434) measure the *in-situ* strength of cohesive soils, which are too soft or sensitive for sampling.

12.2.2.2 *Large shear tests*

These tests may be necessary under special foundation conditions when large specimens of the foundation material are to be tested for better simulations of field conditions and representation of the material which is not possible under laboratory tests. Special loading and observation set up are required in such tests on the same principles as those for laboratory tests.

12.3 Permeability Tests

12.3.1 Permeability of a soil rockmass is the property which governs the rate at which water can flow through unit area under unit hydraulic gradient. A knowledge of permeability is necessary in estimating seepage through the foundation and in determining any foundation treatment that may be needed.

12.3.1 Permeability is usually determined by, *in-situ* pumping in and pumping out tests [*see* IS 5529 (Part 1) and IS 5529 (Part 2)] in wells. The tests are of great importance in case of earth dams, particularly where the foundation is not sufficiently impervious, and hence, they should be performed in sufficient number covering the entire area. In rock foundations also, water loss tests are done in sufficient number of exploratory drill holes.

12.4 Measurement of Density of Foundation Material

12.4.1 *In-situ* density of foundation material is used in stability analysis. It also affords information on the state of compaction and to decide whether further compaction is needed.

12.4.2 The sand density method is used to determine the *in-situ* density by excavating a hole from a horizontal surface, weighing the material excavated and determining the volume of the hole by filling it with calibrated sand [*see* IS 2720 (Part 28)]. Other methods for the determination of *in-situ* density are the core cutter method [*see* IS 2720 (Part 24] and the rubber balloon method [*see* IS 2720 (Part 34)]. The water content [*see* IS 2720 (Part 2)] of the soil at the place of determination of *in-situ* density is needed to calculate the dry density of the soil.

12.4.3 This test is applicable to very shallow depths only, or to the depths of pits and trenches, where the tests are performed at their bottoms. The density determination at depth should be made from undisturbed samples obtained from depths, or by deep penetration tests in non-cohesive soils. In case of dams, surface tests have hardly any significance; hence this may be performed in pits and trenches.

12.5 Blasting Test

12.5.1 Blasting test is often performed in foundations of saturated loose non-cohesive soils mainly for assessment of the likely chances of liquifaction and settlement in the event of earthquake, and also as prototype test for studying the efficacy of blasting as means of compaction of non-cohesive soils, where compaction is considered necessary or desirable.

12.5.2 The test consists in blasting charges of different strength and at different depths and measuring induced accelerations, pore pressure rise and settlements or heave at different points. No standards can be laid down for the detailed procedure and strengths and depths of charge, and these factors have to be decided taking into consideration the past work on the subject and characteristics of the particular site and the proposed structure. This is a special investigation, which may not be needed in all cases.

13 SAMPLING

13.1 The methods employed for enabling collection of samples for visual examination and for performance of laboratory tests thereon have already been described in **9** to **13**.

13.2 To take undisturbed samples from bore holes, properly designed sampling tools shall be used. These differ for cohesive and non-cohesive soils and for rocks. Special samplers like piston samplers and/or the freezing or grouting techniques may have to be employed in cases where samples are to be collected from cohesionless sand which cannot be sampled by ordinary equipment and methods, particularly those existing below ground water table.

13.3 Sufficient quantity of representative undisturbed samples for foundation exploration shall be collected for carrying out the necessary tests.

13.4 While boring small diameter bore holes in foundation area of dams, the total material recovered as core should be collected and stored in core boxes (*see* IS 4078). Samples of soil and rock should be collected and preserved in sealed pint jars to preserve their natural water content. Samples should be representative of the material as it is found in the area.

13.5 In the exploration of the materials in foundations, the excavation from which are in substantial quantities and may be used in embankment construction, samples should be collected representative of each stratum in a volume sufficient to provide about 35 kg of material passing a 4.75 mm IS Sieve. Material smaller than 75 mm should not be removed from this sample.

13.6 Samples collected in the process of routine explorations are not as a rule satisfactory for determination of properties of soil or rock enmasse in its natural condition. For this purpose, samples should be collected of material unaffected by seasonal climatic influence from large diameter bore-holes (100 mm to 150 mm diameter minimum) or from the bottom of open pits.

13.6.1 Bore hole samples should be 300 mm to 600 mm long and open pit samples 250 mm to 300 mm cubes. Every effort should be made to preserve such samples as nearly in their natural condition as possible.

14 LABORATORY EXAMINATION AND TESTING OF SAMPLES

14.1 The samples of soils and rocks collected as described in **13.1** to **13.5** should be examined and tested in the laboratory for determining their engineering properties. The various tests that are usually necessary are given in **14.2** to **14.5**.

14.2 Tests for Soils

14.2.1 *Visual and Manual Examination*

This would give general description of the soil or rock in terms of colour, consistency, structure, lithological type, etc, to help in general classification of the material.

14.2.2 *Natural Moisture Content*

It helps in assessment of foundation pore pressures [*see* IS 2720 (Part 2)].

14.2.3 *Liquid and Plastic Limits*

Liquid and plastic limits are semi quantitative measures of water absorption qualities of clay. They give an indication of the cohesiveness of the soils, and are also useful in soil classification [*see* IS 2720 (Part 5)].

14.2.4 *Specific Gravity*

Specific gravity indicates a basic characteristic of the soil and is useful in calculating several of the soil parameters [*see* IS 2720 (Part 3/Sec 1 and Sec 2)].

14.2.5 *Particle Size Distribution*

A knowledge of particle size distribution is of use for soil classification in understanding the foundation features, such as density, permeability and susceptibility to liquefaction [*see* IS 2720 (Part 4)]. Material must be well graded for dam construction and have a grain size distribution depending upon rock strength and tendency to breakage.

14.2.6 *Bulk Density*

Knowledge of bulk density is essential for computing stability.

14.2.7 *Permeability*

A knowledge of permeability of different foundation strata is essential for estimating general seepage loss, piping danger and grouting requirements. It is also essential for the, design of under seepage control measures. Ratio of horizontal to vertical permeability can indicate the degree of homogeneity and isotropy of the granular foundation material.

14.2.8 *Consolidation Characteristics*

These are required for estimating the magnitude and rate of settlement due to consolidation of soil and for assessment of pore pressure development during construction. One dimensional consolidation test [*see* IS 2720 (Part 15)] is also used for determining the additional consolidation which occurs in a soil, placed at a particular moisture content when it gets saturated. A series of such tests at different moisture contents helps determine the appropriate placement moisture percentage. Pore pressure development can be calculated from data of one dimensional test, or directly by use of three dimensional consolidation test.

14.2.9 *Swelling Tests*

Swelling tests are useful for clays particularly those of montmorillonite family to assess likely pressures the clay would exert on saturation. These tests should be conducted at the lowest moisture content that may be obtained in the field.

14.2.10 *Strength Characteristics*

Strength characteristics of soil may be determined by unconfined compression test [*see* IS 2720 (Part 10)], direct shear test [*see* IS 2720 (Part 13)] and triaxial shear test. Unconfined compression test is generally suitable for rock samples for determination of foundation strength. Strength characteristics of undisturbed soil samples from foundations are usually determined by triaxial shear test or direct shear test (different types being used for different conditions of stability analysis).

14.2.11 *Compaction Test*

May be required for comparison with *in-situ* densities [*see* IS 2720 (Part 7)].

14.2.12 *Density Index (Relative Density)*

For cohesionless soil to assess the degree of compaction of the soil *in-situ* [*see* IS 2720 (Part 14)].

14.2.13 *Minerological Composition*

By differential and X-ray difraction studies. May be required for expansive soils combined with low height dams.

14.2.14 *Chemical Analysis*

Chemical tests may be performed on one or two typical soil samples to determine soluble salt content [*see* IS 2720 (Part 21)], calcium carbonate content [*see* IS 2720 (Part 23)] and organic matter content [*see* IS 2720 (Part 22)].

14.2.15 *Dispersive Test*

Presence of dispersive clays leads to disperse or flocculation in the presence of water which becomes turbid as dispersion progresses. Soil classes have to be evolved on this and necessary precautions undertaken for use of the same material.

14.3 Tests for Rock

14.3.1 *Petrographic Study*

Petrographic study of the rock done by petrographer helps to evaluate the stability of the constituent minerals under conditions of prolonged saturation of the foundation material (*see* IS 1123). These may be required in special cases.

14.3.2 *Shear Strength Tests*

Shear strength tests may be required in the case of weak and layered rock foundations.

14.3.3 *Specific Gravity and Porosity*

This would indicate the state of denseness of the rock (*see* IS 1122).

14.3.4 *Water Absorption*

This test determines the capacity of rock for absorbing water (*see* IS 1124).

14.4 Chemical Analysis

Chemical tests may be performed on one or two typical rock samples to determine soluble salt content, calcium carbonate content and organic matter content.

14.5 Water Analysis

Chemical analysis of river water and ground water including determination of *p*H value (*see* IS 3025) may be done to assess the effects of water, such as corrosion, on underground, or other hydromechanical installations and leaching of salts from the foundation strata or deposition of salts from the percolating water underground.

15 RECORDING AND REPORTING OF DATA

15.1 General

Information collected from the explorations mentioned should be recorded and presented in a concise and systematic manner, suitable for convenient use, in the form of maps, subsurface sections, etc. The locations of sections and points of exploration should be clearly indicated on a map. Pits, trenches, drifts, shafts, different types of bore holes, etc, should be indicated on location maps using suitable symbols as given in IS 7422 (Parts 1 to 5).

15.1.1 The scales used for maps should be in accordance with IS 15686.

15.2 Logging of Pits, Trenches and Holes

15.2.1 *Location*

Every pit, trench and hole should be definitely located on a map by being tied to a co-ordinate grid system. The top elevations should be recorded, as also the inclination of the inclined holes.

15.2.2 *Identification*

The holes, pits, etc, should all be numbered normally in the order in which they are drilled and with suitable symbols as given in IS 7422 (Parts 1 to 5).

15.2.3 *Logs*

A standard and exhaustive log form should be used giving as much information as possible (*see* IS 4453 and IS 4464)

15.2.4 *Description of Soils*

The soils should be described in the logs and in the records according to IS 1498.

15.2.5 *Description of Rock Cores*

The description of the rock core should include its typical name followed by data on its lithologic and structural features, physical conditions, and any special geologic, mineralogic, or physical features pertinent to interpretation of the subsurface conditions (*see* IS 4464).

15.3 Subsurface Sections

Sections showing subsurface conditions believed to exist should be prepared. The locations of the sections should be selected in a manner such that the information is presented in the best possible manner. With different information like type and nature of subsurface material, natural moisture content, density, permeability, etc, shown for different strata, the sections present very useful data for design studies.

ANNEX A

(*Clause* 2)

LIST OF REFERRED INDIAN STANDARDS

IS No.	*Title*
2 : 1960	Rules for rounding off numerical values (*revised*)
1122 : 1974	Method of test for determination of true specific gravity of natural building stones (*first revision*)
1123 : 1975	Method of identification of natural building stones
1124 : 1974	Method of test for determination of water absorption, apparent specific gravity and porosity of natural building stones (*first revision*)
1498 : 1970	Classification and identification of soils for general engineering purposes (*first revision*)
1892 : 1979	Code of practice for subsurface investigations for foundations (*first revision*)
2131 : 1981	Method for standard penetration test for soils (*first revision*)
2720	Method of test for soils:
(Part 2) : 1973	Determination of water content (*second revision*)
(Part 3/Sec 1) : 1980	Determination of specific gravity, Section 1 Fine grained soils (*first revision*)
(Part 3/Sec 2) : 1980	Determination of specific gravity, Section 2 Fine, medium and coarse grained soils
(Part 4) : 1985	Grain size analysis (*second revision*)
(Part 5) : 1985	Determination of liquid and plastic limit (*second revision*)
(Part 7) : 1980	Determination of water content-dry density relation using light compaction (*second revision*)
(Part 10) : 1991	Determination of unconfined compressive strength (*second revision*)
(Part 13) : 1986	Direct shear test (*second revision*)
(Part 14) : 1983	Determination of density index (relative density) of cohesionless soils (*first revision*)
(Part 15) : 1965	Determination of consolidation properties (*first revision*)
(Part 21) : 1977	Determination of total soluble solids (*first revision*)
(Part 22) : 1972	Determination of organic matter (*first revision*)
(Part 23) : 1976	Determination of calcium carbonate (*first revision*)
(Part 24) : 1976	Determination of cation exchange capacity
(Part 28) : 1974	Determination of dry density of soils in place, by the sand replacement method (*first revision*)
(Part 29) : 1975	Determination of dry density of soils in-place by the core-cutter
(Part 34) : 1972	Determination of dry density of soils in-place by rubber-balloon method
3025 : 1964	Method of sampling and test (physical and chemical) for water used in industry
4078 : 1980	Code of practice for indexing and storage of drill cores (*first revision*)
4434 : 1978	Code of practice for *in-situ* vane shear test for soils (*first revision*)
4453 : 1980	Code of practice for subsurface exploration by pits, trenches, drifts and shafts (*first revision*)
4464 : 1985	Code of practice for presentation of drilling information and core description in foundation

IS No.	*Title*
	investigation (*first revision*)
4968	Method for subsurface sounding for soils:
(Part 1) : 1976	Dynamic method using 50 mm cone without bentonite slurry (*first revision*)
(Part 2) : 1976	Dynamic method using cone and bentonite slurry (*first revision*)
(Part 3) : 1976	Static cone penetration test (*first revision*)
5529	Code of practice or *in-situ* permeability test
(Part 1) : 1985	Test in overburden (*first revision*)
(Part 2) : 2006	Code of practice for *in-situ* permeability tests: Part 2 Tests in bedrock (*second revision*)
6403 : 1981	Code of practice for determination of bearing capacity of shallow foundations (*first revision*)
6926 : 1996	Diamond core drilling — Site investigation for river valley projects — Code of practice (*first revision*)
7422	Symbols and abbreviations for use in geological maps, sections and subsurface exploratory logs:
(Part 1) : 1974	Abbreviations
(Part 2) : 1974	Igneous rocks
(Part 3) : 1974	Sedimentary rocks
(Part 4) : 1985	Metamorphic rocks
(Part 5) : 1992	Line symbols for formation contacts and structural features
15662 : 2006	Geological exploration for gravity dams and overflow structures — Code of practice
15681 : 2006	Geological exploration by geophysical method (seismic refraction) — Code of practice
15686 : 2006	Recommendations for preparation of geological and geotechnical maps for river valley projects
15736 : 2006	Geological exploration by geophysical method (electrical resistivity) — Code of practice

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